International Journal of Advanced Research in Engineering Technology & Science
ISSN: 2349-2819
Impact Factor: 7.10
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Email: editor@ijarets.org Volume-11, Issue-10 October – 2024 www.ijarets.org

OPTIMIZING FOUNDATION DESIGN WITH MICROPILING: A PRELIMINARY APPROACH

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ABSTRACT

Micro piles are a type of deep foundation element made from high-strength, small-diameter steel casing and threaded bars. They are effectively utilized in various ground improvement applications to enhance bearing capacity and strengthen existing foundations. The advantages of micro piles include their high load-carrying capacity, minimal site constraints, and self-sustaining operation. This piling system is appealing to both developers and foundation designers. Additionally, the light and compact drilling rigs, along with other ancillary equipment like grout mixers and grout pumps, are also of a compact size. Micro installations can reach depths of hundreds of feet, with each pile capable of supporting several tons of load. Micro piles transfer loads through liquefiable soil to competent bearing strata, meeting design requirements. This paper presents a case study where micro piles with a diameter of 300 mm and a depth of 20 m were used to enhance the bearing capacity of foundation soil and rehabilitate the entire building foundation system.

Keywords: Design, Soil, Concrete, Construction, Sustainable.

INTRODUCTION

Micro piles are drilled cast in place friction piles whose diameter range from 50mm to 300mm therefore the piles sometimes called root piles, pin piles or needle piles. The conceptual idea behind this important technological development was to create a type of pile that would be able to carry large loads while causing minimal vibration or disturbance to in situ materials at the time of installation. The rigs required to install these piles are often relatively small. Because of these important advantages, micro piles have been mostly used in seismic retrofitting, in the rehabilitation of foundations of structures that are very sensitive, and in locations with low headroom and severely restricted access conditions. Furthermore, micro piles have been increasingly used, not only as underpinning foundation elements, but also as foundations for new structures. Prevalent design methods for micro piles are adaptations of methods originally developed for drilled shafts. However, installation of micro piles differs considerably from that of drilled shafts, and micro piles have higher pile lengthto diameter ratios than those drilled shafts. Improved understanding of the load-transfer characteristics of micro piles and the development of pile settlement estimation tools consistent with the load-transfer response of these foundation elements is needed Micro piles, are often used for underpinning. They are also used to create foundations for a variety of project types, including highway, bridge and transmission tower project. They are especially useful at sites with difficult or restricted access, or with environmental sensitivity. Micro piles are made of steel with diameters of 50 to 300 mm. installation of micro piles through top soil sand and cobblestones overburden and into soil rock can be achieved using air Rotaryor Mud Rotary or Mud drilling, impact driving, jacking, vibrating or screwing machinery.

Strengthening of foundations of existing buildings in earthquake zone megacities and addition of new floors to existing buildings due to sky- high land values in big cities, usually need excavation and temporary support system below the foundation level. This is difficult not only due to limited head room and access in congested area but also for the risk of collapse of the structure during the excavation process itself. Moreover, underground spaces need to be utilized for alternate modes of transport. Micro piles may be used economically in such situations. Micro pile is small diameter (less than 300 mm) and 20 to 30 m in length, grouted drilled pile. The grout is either placed or injected under pressure (grouting pressures above 0.8 to 1

Mpa). It consists of a continuously threaded hollow reinforcing tendon as a load carrying steel member together with a grout body of furnace (Portland) cement which allows transfer of tension and compression forces mainly from the friction of the threaded tendon via the grout body into the surrounding soil. Due to high pressure grouting, there is insignificant shrinkage between the pile and the soil. The penetration of the fluid part of the cement mix into the surrounding soil creates a transitory zone between the body of the Micro pile and the soil leading to a strong grout/ground bond. Due to this reason ultimate load carrying capacity of Micro pile is higher than anticipated capacity based on conventional bearing capacity theory. Micro piles are typically used for structural support. It is usually installed for bridge and building foundations supports and seismic retrofits. Another main application of Micro pile is soil reinforcement e.g. slope stabilization/earth retention projects. The basic philosophy of Micro pile design differs little from that required for any other type of pile. The system must be capable of sustaining the anticipated loading conditions with the pile components operating at safe stress level and with resulting displacements falling within acceptable limits. For conventional piling systems, the large cross sectional area results in high structural capacity and stiffness, hence the design is normally governed by the geotechnical load carrying capacity. Due to the micro piles small cross-sectional area the Micro pile design is more frequently governed by structural and stiffness considerations. The emphasis on structural pile design is further increased by the high grout to ground bond capacities that can be attained using pressure grouting techniques.

LITERATURE REVIEW

Sharma Binu, Hussain Zakir 2011 "A Model study of Micro pile groups subjected to lateral loading condition". Vol 4, ISSN 196-205, July-2011. [6]

In this case study the use of Micro piles as a structural support or retrofitting approach may be regarded as a technically and economically sound option. Micro piles are tiny diameter piles that have an annular grout surround that is in touch with the earth and a core steel component. Due to its extensive use, it is vital to investigate the interaction of soil Micro piles under diverse loading scenarios. In order to conduct the examination, a model experimental study of group Micro piles with varying length to diameter ratios that are implanted in a bed of sand with a relative density of 50% and exposed to lateral loading conditions is used. It has been discovered that the length to diameter ratio is a key factor affecting the groups final level of lateral resistance. Changing from a small pile to along pile in groups of Micro piles.

Elarabi Hussein 2024 "Micropiles for Structural Support" ISSN: 2277-9655 December, 2014. [01] Micropiles are small diameter piles (less than 300 mm) can be installed in almost any type of ground where piles are required with design load (3 Tons to 500 Tons). The first use of micropiles dates back to the early 1950's in Italy, where new methods of underpinning for existing structures were needed to restore structures and monuments damaged during World War II (Lizzi, 1982).

Loehr J Erik, Browders John, & Underwood Michael (2019) "Response of Micro piles in earthslopes from large scale physical model test", Volume 2021, ISSN 6687124 (2009) [4].

This research paper describes strengthening of slope stabilization because slope failure can result from a variety of sources, and they can significantly affect both the public and private infrastructure. A relatively recent technique for slope stabilization called micro piling has been embraced by serval organisations and employed at numerous problematic areas across the world. micro piling design may be overly conservative due to lack of understanding regarding weight transformation for pile within moving soil, albeit this is not always the case. The goal of the study that is being presented is to offer the necessary experimental data to enhance the estimation of the limit load for Micro pile in application of slope stabilisation. The goal is to offers direction on the impact of pile batter and spacing so that designers may appropriately take these effects into consideration when anticipating the limit resistance values.

Bhardwaj Sunil and Singh S.K., (2014), "Experimental studies on model Micro pile under oblique pull out load". ISSN-8441-9059 (2014) [9].

In this paper we determine the vertical Micro pile's pull-out capacity under oblique loads, experimental research on model Micro piles was conducted in the field.25 mm-diameter Micro piles with embedded lengths of 300, 400, and 600 mm in silty sand, mm (L/D -12, 16 and 24) were auger drilled and cast (SM soil). At the middle of each borehole, reinforcement in the form of 10 mm Tor steel bar was installed. A pipe was used to pour well mixed, neat cement water grout with a 0.45 w/c ratio into boreholes. Ample cured Micro piles were evaluated with progressive pull-out loads applied at 0 degrees, 5 degrees, 10 degrees, 15 degrees, 20 degrees, 30 degrees, 45 degrees, and 90 degrees with respect to the vertical axis of the Micro piles. Final pull out capacity for each load inclination.

Houhou Mohamed Nabil et. al, 2023, "3D numerical analysis of pile response due to soil movements induced by an adjacent deep excavation" Vol. 19, Issue 6, pages 854 – 870, ISSN: 1708-5284, 5 December 2023 [10]

This paper aims to investigate single pile and pile group responses due to deep braced excavation-induced soil movement in soft clay overlying dense sand. The analysis focuses first on the response of vertical single pile in terms of induced bending moment, lateral deflection, induced axial force, skin resistance distribution and pile settlement. To better understand the single pile behaviour, a parametric study was carried out. To provide further insights about the response of pile group system, different pile group configurations were consider

METHODOLOGY

1. Drilling

Most drilling methods selected by the specialty contractor for a Micro pile project are likely to be acceptable on a particular project, provided they can form a stable hole of the required dimensions and within the stated tolerances, and without detriment to their surroundings. It is important not to exclude a particular drilling method because it does not suit a predetermined concept of how the project should be executed. It is equally important that the drilling contractor be knowledgeable of the project ground conditions, and the effects of the drilling method chosen.

2. Flushing

Cleaning of bore hole to flush out sludge, mud or loose material underground. Air vs. Water – Rotary vs. Rotary Percussion • Guideline for selection: − Provide clean hole − Enhance penetration rate − Minimize tool wear − Consistent with purpose of hole − Minimal damage to formation and/or structures Environmentally compatible Reconsider options if “lost flush” occurs.

3. Casing.

Circular MS plate casing provide to maintain alignment and verticality. The micropile casing generally has a diameter in the range of 3 to 10 inches. Typically, the casing is advanced to the design depth using a drilling technique. Reinforcing steel, typically an all-thread bar is inserted into the casing. High-strength cement grout is then pumped into the casing

4. Reinforcement

Reinforcement may be placed either prior to grouting, or placed into the grout-filled borehole before the temporary support (if used) is withdrawn. It must be clean of deleterious substances such as surface soil and mud that may contaminate the grout or coat the reinforcement, impairing bond development. Suitable centralizers should be firmly fixed to maintain the specified grout cover.

5. Grouting

The grout usually comprises a neat cement mix with w/c ratio between 0.45 and 0.50 by weight. Additionally, sanded mixes of up to 1:1 or 2:1 sand: cement ratio has been used in European practice, but they are becoming less common due to a growing trend towards the use of higher grouting pressures involving neat cement grouts. Gravity fill techniques tend now to be used only when the pile is founded in rock, or when low-capacity piles are being installed in stiff or hard cohesive soils, and pressure grouting is unnecessary.

6. Capping

Top Surface anchorage with capping beam for foundation**.**

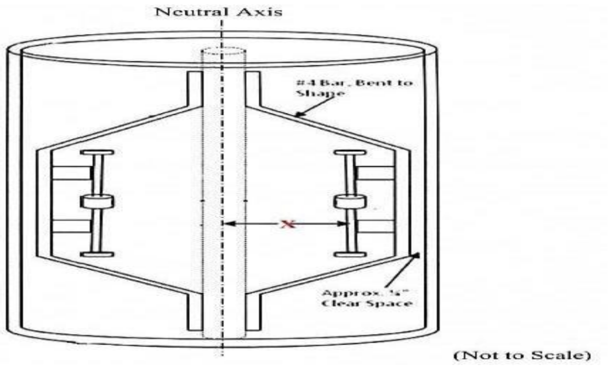


Figure 2: Strain Gages Location (Kershaw, 2011).

Table 1: Micropiles’ Properties.

Property or Dimension	Value	Unit
OD_{casing}	9.625	in.
Id_{casing}	8.681	in.

$(Dia)_{bar}$	2.5	in.
E_{steel}	29000	ksi
f'_c	5	ksi
E_{grout}	4030	ksi

Table 2: Micropile Cased Zone Properties.

Property or Dimension	Value	Unit
A_{casing}	13.57	in^2
A_{bar}	4.91	in^2
A_{grout}	54.28	in^2
η	7.20	
$A_{trans,steel}$	26.02	in^2
$A_{trans,grout}$	187.25	in^2
$A_{composite}$	72.76	in^2
$E_{composite}$	10373	ksi
$I_{composite}$	421.28	$in.^4$

Table 3: Micropile Bond Zone Properties.

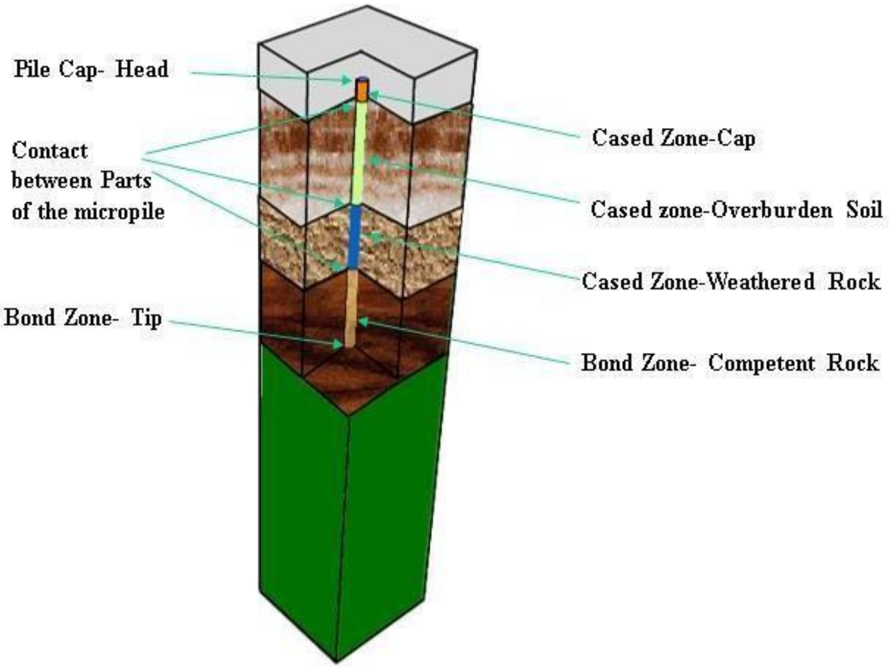
Property or Dimension	Value	Unit
A_{casing}	0.00	in^2
A_{bar}	4.91	in^2
A_{grout}	67.85	in^2
H	7.20	
$A_{trans,\ steel}$	14.34	in^2
$A_{trans,\ grout}$	103.17	in^2
$A_{composite}$	72.76	in^2
$E_{composite}$	5715.00	ksi
$I_{composite}$	421.30	$in.^4$

Micropiles -Soil & Rock Interaction Mechanism

Contact and interaction mechanisms are the most important in the model since they are responsible for the load transfer mechanism between the micropile and the ground. In this model, the interaction can be classified into the following categories (shown in Figure 4.5); Interaction of the pile cap-pile.

- Interaction between steel casing and ground (soil) in the cased zone. This comprises the interaction between the of steel casing - overburden soil, steel casing-weathered rock, and 1 foot extensions of the steel casing into the rock. The one foot embedment is a condition necessary in the design.
- Interaction between the grout and the ground (rock) in the bond zone. This interaction is important as the most of load transfer occurs in this area. It involves the competent material of Met conglomerate and Met sandstone that will ultimately support the bridge.
- Interaction of the pile tip and the ground that involves no relative movement between the pile tip and the ground, so a constraint is applied.
- Interaction that connects all micropile's parts together. To simulate the interaction, a contact pair, surface-to-surface with finite-sliding tracking approach algorithm was selected for the contact. Surface to surface contact consists of

two surfaces, master surface and slave surface. Master surface is taken to be the ground and the slave is the micropile. Master surface nodes is allowed to penetrate the slave surface which requires the micropile to have finer mesh and smaller element sizes than the ground at the contact region, this condition is necessary to avoid penetration of the slave nodes into the master surface (ABAQUS ,2011).



Interaction of Ground with the Micropile (Corvern Engineering, 2010)

Compressive Strength

Table 4

Age (Days)	Compressive Strength (N/mm2)	Consistency
	Flow able (W/P 0.18)	Pourable (W/P 0.165)
1	24	26
3	45	51
7	55	57
28	65	68

Flow Characteristic – The maximum distance of flow is governed by the gap width and the head of the grout. Typical data of flow design assuming grout is poured immediately after mixing is given in the table below.

Grout Maximum Flow distance in mm

Table 5

Consistency	Gap width (mm)	50mm head	100mm head	250mm head
Flowable	30	350	1000	1500
	40	500	1500	2000
	50	900	2000	3000 +

Flexural Strength

Table 6

Age (Days)	Flexural strength N/mm2 (W/P 0.18)
1	2.5

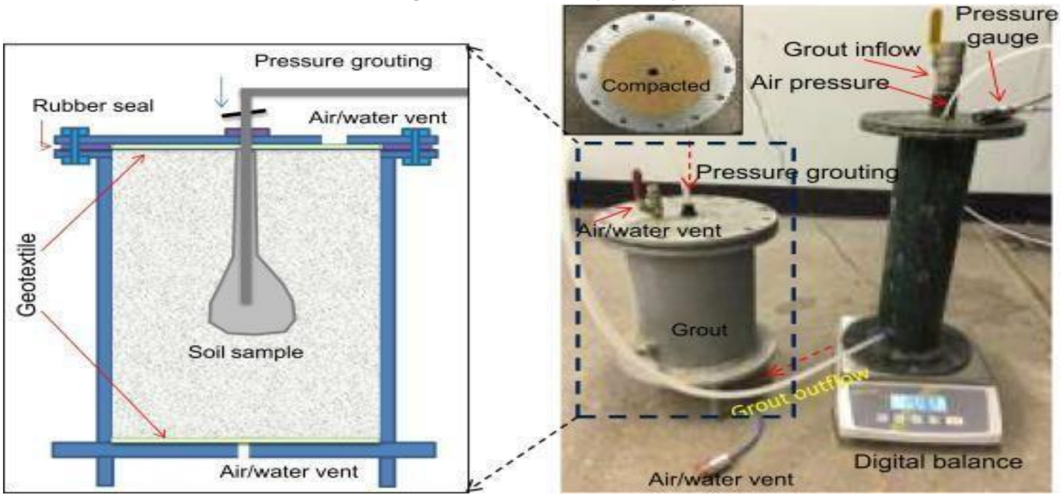
3	7.0
7	9.0
28	10.0

Tensile Strength (W/P 0.18) - 3.5 N/mm2 at 28 days Pullout bond strength (W/P 0.15) – 17 N/mm2 at 7 days 20 N/mm2 at 28 days.

Times for expansion after mixing –Start: 20 minutes Finish: 120 minutes

Fresh wet Density – Approximately 2220kg/m3 depending on actual consistency used Young Modules – 26 KN/mm2.

Figure 3: Pressure grouting



MICRO-PILE CONSTRUCTION COST

The principal material components of Micro piles include threaded steel casings, cement grout, steel reinforcing bars, and centralizers. Because of higher load capacities that continue to be achieved by Micro piles, it is clear that costs for structural steel within the Micro pile cross section represent a significant cost component.

Table 7

Sr. No	Material	Weight (kg)	Price (Rs)
1	Cement OPC	50	430
2	Sand	50	180
3	Cibex 100	255 grams	200
4	25mm Dia Steel bar 9mtr length	34	9000
5	8mm Dia Steel bar 27mtr length	13	550
6	300mm M.S Plate Casing 9mtr length	45	2000
	Total		12360

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MICRO PILE LABOUR COST

Table 8

Sr. No	Labour	Nos	Price
1	Fitter	3	900
2	Welder	1	350

3	Helper	4	1000
	Total		2250

CASE STUDY

Load carrying capacity

As per site condition 2 number of pile set carrying above column load 240Kn Diameter = 300mm

Depth = 6 mtr

Calculate Ultimate load capacity **Pu = Ab. Sub, Nc + Ap. Sus. α**

Where,

Ab = Area of base

Sub = surface strength of clay at base shaft

Nc = Bearing coefficient

Ap = Surface area of shaft

Sus = Shear strength of clay of shaft Ab = 3.142 x 0.3^2 = 0.070 m^2

Ap = 3.142 x 0.3 x 7 = 6.59 m^2

Sub =200

Kn Nc = 9

Sus = 40 Kn α = 0.45

∴ Ultimate Bearing Capacity (Pu) = Ab. Sub. Nc + Ap. Sus. A

= (0.070 x 200 x 9) + (6.59 x 40 x 0.45)

= 126 + 118.62

Pu = 244.62 Kn …… for single pile

Safety factor = 2

Working load capacity = 244.62 / 2 = 122.31 kn ……. for single pile Load of column carrying by single pile,

Load of Column = 240 kn Number of pile = 2

∴ 240/2 = 120 Kn < 122.31Kn ……. **Hence Safe**

Base bearing capacity 126 Kn > Skin Friction capacity 118.62 Kn

RESULTS AND DISCUSSION

Micro piles are largely used for increasing the bearing capacity of the soil and also in marshy and sandy areas. It could prove a useful for high rise buildings where area is congested and the bearing capacity of the soil is also relatively low. Seismic retrofit and preventing harmful settling are important for foundation underpinning. Micro piles are frequently used as underpinning in specific Micro piling is done on this site to improve the bearing capacity of soil as micro piling is ideal for such conditions. Various types of advanced tools are also done on this site. The number of piles is 110 which surrounds the outer edges of the site. Theses piles basically provides strength to the soil and in turn improves the bearing capacity. The structure is 61 floors and is under construction. Reinforcement is provided up to 9m depth.

Grouting- 1bagof cement (50kgs) +24litre of water+100gms of GP2 Due to the full bonding, the piles acted as both ground reinforcement and structural supports to significantly reduce the rate of settlement of this major structure. They are also well suited for foundation under- pinning, arresting ground movements, and increasing the capacity of existing foundation.

Table 9

Sr. No	Grade	Age indays	Cube size	Weight(KG)	Load(KN)	Compressive strength (Mpa)	Average
1	GP2	7	70.60 x 70.60 x 70.60	0.816	240	48.19	
				0.821	252	50.60	49.60

			mm	0.807	249	50.00	
2	GP2	28	70.60 x 70.60 x 70.60 mm	0.807	307.9	61.83	61.77
				0.804	310.8	62.41	
				0.814	304.2	61.08	

Table 10

Sr. No	Grade	Agein days	Cube size	Weight(KG)	Load (KN)	Compressive strength (Mpa)	Average	Percentage
1	M30	7	150 x 150 x 150 mm	8.36	522.38	23.22	22.27	74.24
				8.34	500.65	22.25		
				8.48	480.37	21.35		
2	M30	28	150 x 150 x 150 mm	8.22	740.16	32.90	33.33	111.12
				8.14	760.52	33.80		
				8.67	749.42	33.31		

The additional required frictional resistance of 900 kN from the micro pile system is derived based on considering an element of soil at the micro pile-soil interface and integrating the element resistance over the entire length of micro pile. The vertical component of the frictional resistance at the interface opposes the applied load on the footing.

CONCLUSION

Micro pile is versatile in situ ground improvement method and has been used highly effectively in numerous stability issues. API Pile system offers satisfactory compression behavior in the context of lateral stability and vertical displacement. Tension pile can be economically strengthened by a bars system. The commercial development of micro piles has been a stimulus to the material suppliers creating new pile materials, drilling techniques and monitoring tools. Micro pile can be a very expensive means of supporting lateral load and bending movement. Developments like enhanced duplex drilling tools, rotary-sonic drilling, and hollow core bars, seem to be economically viable. We now have very high-capacity micro piles competing favorably with more conventional driven pile and drilled shaft systems. When compared on the basis of cost per KN, micro piles prove to be a highly desirable alternative even for new construction on open ground. Micro piles are also widely employed to enhance the bearing capacity of the soil as well as in marshy and sandy lands. It may be an effective alternative for high rise structures where space is scarce and the bearing capacity of the soil is also comparatively low.

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